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THE EFFECT OF HYBRIDIZATION ON MECHANICAL BEHAVIOUR OF KEVLAR AND NATURAL FIBER REINFORCED COMPOSITE

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ABSTRACT

Fiber Reinforced Polymer (FRP) composite is finding application in many fields such as structural elements, roof panels, wind mill blades etc., due to its low cost, high strength to weight ratio and stiffness to weight ratio. In this paper, initially four varieties of FRP reinforced with natural fibers like jute, flax, sisal and hemp have been numerically studied under modal analysis and static structural analysis by using ABAQUS/CAE-6.14 software.

Moreover, numerical simulation and experimental analysis were carried out by replacing top and bottom natural fabric layer by Kevlar-29, keeping the same core of natural fibers. The substantial increase of around 54% in natural frequency and 20 % in flexural strength were observed in the hybrid FRP compared to Natural fabric FRP. The panels were fabricated by vacuum bagging technique and the volume fraction of fibers was 38%. Amongst all the varieties of FRP panels under study, the hybrid panel made of kevlar and hemp showed maximum natural frequencies of 27.5 Hz, 139.9 Hz and 358.4 Hz with encouraging damping factor of 1.56, 0.60 and 0.005 at three flexural modes, respectively. Also, it has maximum flexural strength of 244.2 MPa.

KEYWORDS: *Natural Fiber, Damping, Natural Frequency, Fiber Reinforced Polymer & Vibration*

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Original Article

INTRODUCTION

Hybrid FRP made of natural and synthetic fibers has a great potential in application areas like wind mill, roof panels and structural elements, and should possess mechanical as well as dynamic vibrational stability [1]. The structural elements used in these types of applications are exposed to varied dynamic load conditions [2]. The proper arrangement of fabric in making hybrid FRP has many benefits like light weight, high strength-stiffness, lower cost and bio-degradability [1]. To achieve right combination, the strength and dynamic characteristics study is important to put such FRP in applications by analysing mechanical strength, natural frequency, mode shapes and damping factors [3]. Numerical simulation and modal analysis are the essential tools for researchers to study these parameters.

The alkaline pre-treatment of natural fibers is necessary, to improve the desired mechanical and damping properties by providing better interlocking between fibers and matrix material in sisal and banana FRP. Flexural modulus improved up to 50 wt.%. FRP made of sisal and natural frequency from 24 Hz to 633 Hz with the

damping ratio of 0.11 to 0.40 is observed in vibration modal analysis [4]. Coconut made FRP shows the enhancement in natural frequency after such chemical treatment [5]. The same improvement is observed in basalt reinforced composite, fabricated using hand lay-up technique by J Alexander et al. using ABAQUS software. Tensile properties of basalt FRP are better than Glass FRP [6]. Free vibration modal analysis study on jute FRP resulted in the natural frequency ranging from 72.5 Hz to 243.2 Hz using FEA software [7]. The natural frequency in Owen fabric based FRP is found better than unidirectional FRP. The damping without compromising on its stiffness totally depends upon the orientations of fiber lay-ups [8]. Coconut sheath FRP were also studied by K. Senthil Kumar et al. and found the natural frequency of 21 Hz to 177 Hz with damping factor of 0.09 to 0.481. Effect on tensile and impact strength was also studied after silane chemical treatment [8]. Reinforced composite made of flax natural fibers shows 51.03% better damping than glass reinforced composite. The specific flexural strength and modulus of flax reinforced composite were also at par with glass FRP [9]. The natural frequency of around 200 Hz with damping ratio of 0.14 was found by A. Etaati et al. on short 30 % wt. hemp fiber thermoplastic composite [10]. Using FFT analysis in modal analysis hemp FRP showed better results in comparison with all other FRP's along with the strength and modulus [11].

The structural vibration analysis on aircraft wing made of natural fibers reinforced with epoxy matrix shows better natural frequency and buckling factor [12]. The FRP fabricated with bi-directional orientated fibers of hemp, flax and sisal shows superior results than unidirectional fiber FRP using ANSYS 15.0 software. The chemical treatment increases the modulus and stiffness of the composite [13]. Referring various journal papers, the FRP shaft fabricated from synthetic fiber kevlar shows highest frequency of 74 Hz to 1245 Hz for three modes in modal analysis by P. Bhirud[3] et al., and on the other hand, natural frequency of FRP fabricated from natural fibers shows lower natural frequency as depicted in Table 1. So, there is more scope for improvement of natural frequency when both synthetic and natural fibers are reinforced to make hybrid FRP, and there is no evidence of such type of configuration in making FRP composite.

Table 1: Literature Data of FRP Composite

Sr. No.	FRP	Frequency(Hz)			Ref.
		Mode 1	Mode 2	Mode 3	
1	Kevlar-FRP	74.56	458.09	1245.2	[3]
2	Jute-FRP	72.5	201.39	243.54	[7]
3	Flax-FRP	50.76	157.6	367.79	[13]
4	Sisal-FRP	24	233	633	[4]
5	Hemp-FRP	22.1	40.76	130.67	[11]
6	Coconut-FRP	21.92	177.37	-	[8]
7	Basalt-FRP	14.64	122.89	315.19	[14]

In the present work, four varieties of FRP specimens made of jute, flax, sisal and hemp were studied under vibration modal analysis and static structural analysis. Moreover, the influence of addition of kevlar fabric as outer face sheets was also studied through ABAQUS/CAE 6.14 software and FRF analyser.

MATERIALS AND METHODS

Constituent Materials and Fabrication

Initially, four kinds of FRP panels reinforced with natural fibers were fabricated using Vacuum bagging method, which comprises of six layers of fabric, as per the stack configuration shown below.

- Jute/Jute/Jute/Jute/Jute/Jute – Jute-FRP
- Flax/Flax/Flax/Flax/Flax/Flax – Flax-FRP

- Sisal/Sisal/Sisal/Sisal/Sisal/Sisal – Sisal-FRP
- Hemp/Hemp/Hemp/Hemp/Hemp/Hemp – Hemp-FRP

The epoxy resin 520F and hardener E-758 in the ratio of 10:1 is used to make the composite. The vacuum pressure of 0.45 bar was used and the FRP panel was cured for 24 hours at room temperature. The panels are represented as Jute-FRP, Flax-FRP, Sisal-FRP and Hemp-FRP. Again, the FRP panel were fabricated by replacing the top and bottom layer by kevlar-29. These new panels are represented as Jute K-FRP, Flax K-FRP, Sisal K-FRP and Hemp K-FRP. However, the same thickness of 4 mm was maintained. The volume fraction of panels was 0.38.

Theoretical Analysis for Free Vibration

The cantilever beam of FRP composite was considered of size 330 mm x 80 mm x 4 mm with rectangular cross section. The natural frequencies of Jute-FRP, Flax-FRP, Sisal-FRP and Hemp-FRP were determined using Euler-Bernoulli beam theory for first three modes as shown in Figure 1.

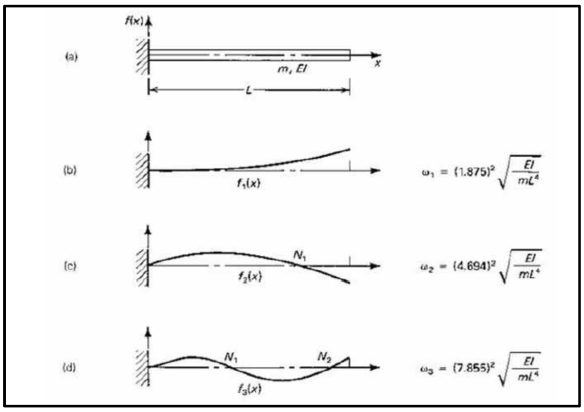

Figure 1: Undamped Natural Frequencies and Corresponding Mode Shapes [15, 16]

The natural frequency is calculated using [15, 16]

$$\omega = \beta L \sqrt{\frac{EI}{mL^4}} \quad (1)$$

Above equation can be written as

$$\omega = \beta L \sqrt{\frac{EI}{\rho A L^4}}$$

Where ω - Circular frequency (rad/sec), E- Young's modulus, I- Moment of inertia, A- Cross section Area, ρ- Density of material, L-Length of beam, β L –Constant (1.875, 4.694 and 7.855 etc.). The FRP is orthotropic material and properties are shown in Table 2.

Numerical Modal Analysis

The vibrational modal analysis was performed to determine the natural frequency of the FRP composite panels, using ABAQUS/CAE-6.14 software. The layered solid model was generated with the thickness of 4 mm as shown in Figure 2. The 20 noded brick solid elements were used for meshing the above model. The element size was 10 mm along the length and width. Single element was taken along the thickness of each layer and total numbers of elements and nodes

generated in the model were 264 and 2056, respectively. The orthotropic material properties were assigned to each layer, as shown in the Table 2. The required material properties such as modulus of elasticity in the fiber directions (E_x and E_y) are determined from tensile test on Universal Testing Machine (UTM) and other constants were estimated from literature data [1, 4, 7, 8, 11, and 14]

Table 2: Properties of the Different Layers of FRP Panel [1, 4, 7, 8, 11, and 14

Material	Density (Kg/m3)	E_x (GPa)	E_y (GPa)	E_z (GPa)	υ_{xy}	υ_{yz}	υ_{zx}	G_{xy} (GPa)	G_{yz} (GPa)	G_{zx} (GPa)
Kevlar-29/epoxy	1440	29	29	9.3	0.10	0.18	0.18	18	15	15
Jute/epoxy	1300	5.8	5.8	2.4	0.3	0.15	0.15	2.50	1.86	1.86
Sisal/epoxy	1580	5.2	5.2	2.1	0.33	0.2	0.2	1.69	1.25	1.25
Flax/epoxy	1520	8.1	8.1	3.9	0.32	0.2	0.2	2.71	1.90	1.90
Hemp/epoxy	1470	8.5	8.5	4.1	0.26	0.21	0.21	2.75	1.95	1.95

The meshed panel was fixed at one end to simulate the condition of cantilever beam. The natural frequencies and the corresponding mode shapes were determined using Block Lanczos method, inbuilt in the software. The values were compared with the theoretical results, as shown in Table 3. The numerical values matched well with the theoretical values and the maximum error was less than 2%. It validated the numerical model for the vibration modal analysis.

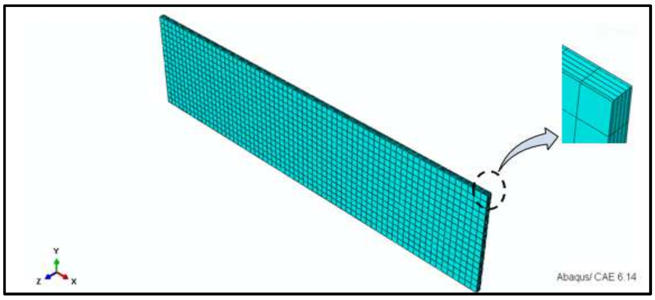

Figure 2: Meshed FRP Model

Table 3: Comparative Table of Modal Frequencies

Natural FRP	Theoretical Frequency, Hz			Numerical Frequency, Hz		
	Mode 1	Mode 2	Mode 3	Mode 1	Mode 2	Mode 3
Jute- FRP	12.53	78.55	219.98	12.71	79.48	222.85
Flax-FRP	13.71	85.95	240.73	13.90	86.91	243.51
Sisal-FRP	10.76	67.72	189.65	10.93	68.35	191.55
Hemp-FRP	14.30	89.46	250.50	14.40	90.09	252.21

The same numerical analysis was repeated for Jute K-FRP, Flax K-FRP, Sisal K-FRP and Hemp K-FRP, where the top and bottom natural fabric layer was replaced with kevlar-29 fabric. A significant improvement in the natural frequency was observed. Further, these panels were critically analyzed through experimentation.

Free Vibration Damping Test Set Up

The free vibration test was carried out on FRF analyzer for detailed analysis of Jute K-FRP, Flax K-FRP, Sisal K-FRP and Hemp K-FRP. The specimen size was 330 mm x 80 mm x 4 mm. It was clamped at one end and the accelerometer was attached at the other end using tape, to sense the acceleration. The impact hammer with rubber tip was

used to give free vibrations to the specimen. The displacement was sensed by accelerometer and a signal was generated by DAQ device, as shown in Figure 3. This is further analyzed through NI DAC chassis 7141(single module chassis), Model 9234(standard dedicated module for sound and vibration measurement) to get the natural frequency and damping factor.

Figure 3: Free Vibration Damping Setup

The hybrid FRP composite specimen was considered as single line object. The test specimen was marked at six points equidistant along length. It was hammered at first point and the reading was saved. The process was repeated at every point. After taking all the readings, the damping factor file was saved as .DAT format for all specimens. For modal parameter identification and analysis, .DAT file was opened in another window as shown in Figure 4, by selecting the mode number and frequency region to get the frequency and its corresponding damping ratio. The series of peaks gave the natural frequency of the FRP panel.

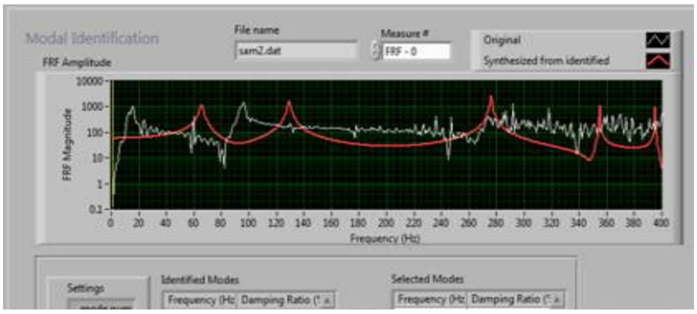

Figure 4: FRF Plot Showing Frequency vs. Magnitude

The damping factor for the material was calculated by using half-power band width method (equation 2), shown in Figure 5.

Damping factor (ξ) = $(f_2-f_1)/2f_n$ (2)

Where, f_1 and f_2 are lower and upper frequency and f_n is the natural frequency.

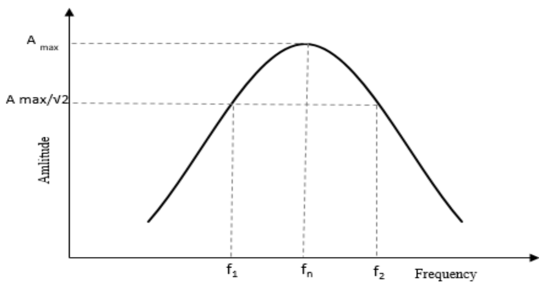

Figure 5: Half-Power Band Width Method

Flexural Test

Three-point bending test was executed on each Hybrid FRP composite specimen. Four experiments were performed on UTM for each type of sample, 110 mm X 20 mm in size as per ASTM D-790. The span length between the lower supporting rollers was kept 70 mm by retaining the ratio of span length to thickness close to 16. A load cell of 1 KN was used on the upper cross head with the loading speed of 1 mm/min.

RESULTS AND DISCUSSIONS

Figure 6 shows the numerical results of natural frequency, at three mode shapes by dashed lines for jute, flax, sisal and hemp FRP, and literature data with continuous lines. The numerically calculated values of natural frequency and literature data are in the range of 0-650 Hz for the first three flexural modes. The thickness of panel under study was 4 mm, but the panels of same thickness were not considered by the researchers. Hence, the variation between numerical values and literature data was observed. For validating the numerical model, the numerical results were compared with theoretical results. The results matched well with less than 2% error. The numerical results showed the maximum natural frequency for hemp FRP.

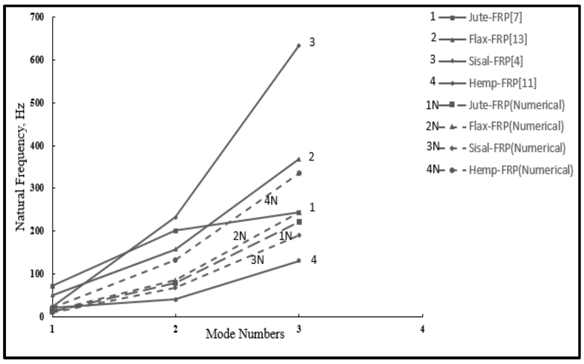

Figure 6: Validation of Natural Frequencies with Literature Data for FRPs

The same numerical analysis was carried out on modified natural fiber FRP with kevlar i.e. Jute K-FRP, Flax K-FRP, Sisal K-FRP and Hemp K-FRP. The % increase in natural frequency for jute, flax, sisal and hemp FRP due to addition of top and bottom kevlar facesheet was 60%, 45%, 70% and 42.5% respectively, as shown in Figure 7.

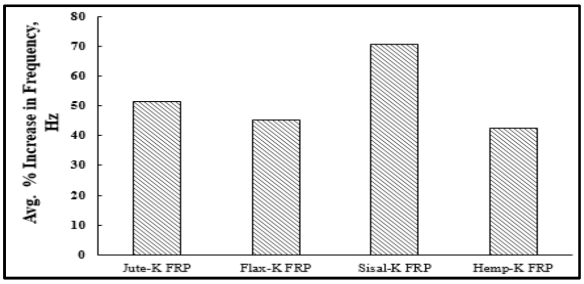

Figure 7: % Increase in Natural Frequency with Kevlar Face Sheet in Hybrid FRP Panel

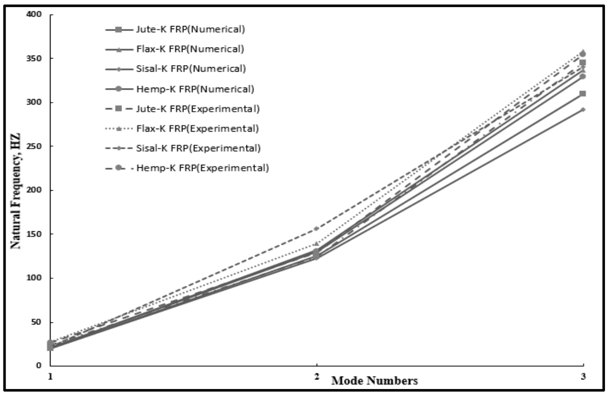

Figure 8: Experimental and Numerical Results of Natural Frequencies of Hybrid FRP

After witnessing the improvement in natural frequencies in hybrid FRP panels by addition of kevlar fabric, free vibration damping was performed on FRF analyzer to find out the experimental results. The natural frequency calculated numerically and experimentally is compared as shown in the Figure 8. Close tolerance was observed in the results. The corresponding mode shapes for first three flexural modes are also shown in Figure 9.

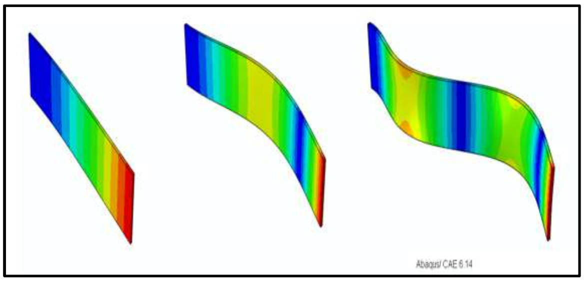

Figure 9: I, II and III Flexural Mode Shapes

The experimentally determined natural frequencies and damping ratio are compared for first three flexural modes and depicted in Table 4. The damping is associated to the molecular mobility within the FRP structure. Lower the degree of mobility, lower is the value of damping ratio which in turn offers better damping properties [14]. From the above results, Hemp-K FRP showed the highest natural frequencies and lower values of damping factor, as compared to other hybrid FRPs.

Table 4: Natural Frequency and Damping Factor for Hybrid FRP

Sr. No.	FRP	Mode I		Mode II		Mode III	
		Natural Frequency(Hz)	Damping ratio (ξ)	Natural Frequency(Hz)	Damping ratio (ξ)	Natural Frequency (Hz)	Damping ratio (ξ)
1	Jute-K FRP	24.2	1.72	124.9	0.77	345.4	0.08
2	Flax-K FRP	26.2	1.8	129.3	0.71	354.8	0.06
3	Sisal-K FRP	22.1	2.78	156.6	1.04	341.6	0.038
4	Hemp-K FRP	27.5	1.56	139.8	0.60	358.4	0.005

The flexural strength corresponding to experimentally determined peak load was calculated by using ANSYS software, and the average flexural strength of FRPs is shown in Figure 10. FRP panels failed in compression under three-point bend test. The average flexural strength for Jute-FRP, Flax-FRP, Sisal-FRP and Hemp-FRP were 179.1 MPa, 187.2 MPa, 141MPa and 195.2 MPa respectively. However, the flexural strength for Jute K-FRP, Flax K-FRP, Sisal K-FRP and Hemp K-FRP were 226.8 MPa, 231.4 MPa, 181.5 MPa and 244.2 MPa, respectively. There are around 20% increases in

flexural strength by addition of kevlar facesheet. The maximum flexural strength was observed for Hemp K-FRP panel.

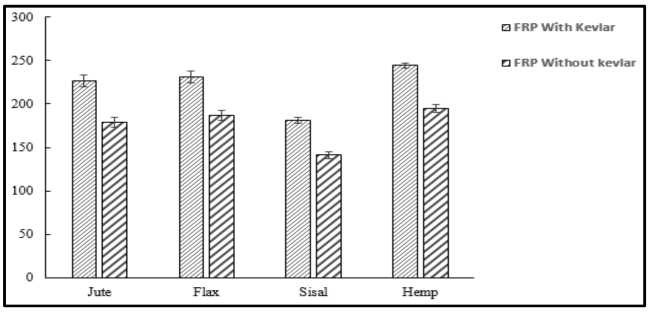

Figure 10: Flexural Strength of FRP Specimens Under Three- Point Bend Test

CONCLUSIONS

Four varieties of FRP panels made of natural fibers such as jute, flax, sisal and hemp were numerically simulated to determine the natural frequency and flexural strength. The analysis was repeated by using kevlar face sheets and the results were observed for the hybrid panels. Among all natural fiber reinforced FRPs, Hemp-FRP was observed to have maximum natural frequency of 21.21 Hz, 132.56 Hz and 336.42 Hz respectively, for the first three flexural mode shapes. There was substantial increase of around 54% of natural frequency and 20% in flexural strength by placing Kevlar face sheet at top and bottom in the modified configuration of FRP. The Hemp-K FRP hybrid panel showed the maximum natural frequency and flexural strength and better damping property. The results assure the use of Hemp K-FRP hybrid panel in prefabricated structural panels.

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